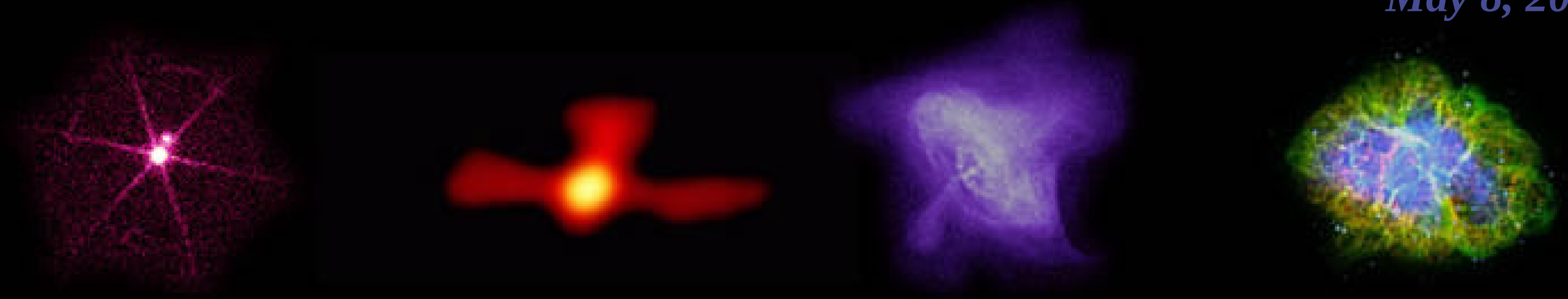
Technology Readiness and Implementation Plan Report

Constellation X
The Constellation X-ray Observatory

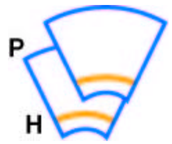
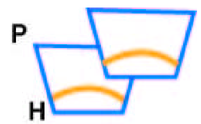
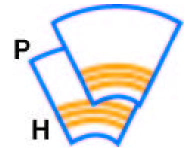
Spectroscopy X-ray Telescope

May 8, 2003



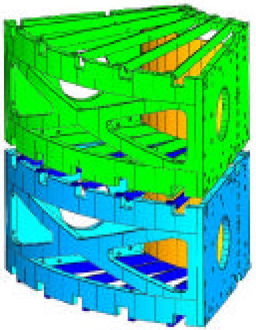
Goddard Space Flight Center

Technology Development Roadmap Summary

	Optical Pathfinder Assembly		Engineering Unit	Mass Alignment Pathfinder	Prototype	
	OAP #1	OAP #2				
Configuration						
Module Type	Inner	Inner	Inner	Inner	Outer	Wedge (2 Outer & 1 Inner)
Housing Material	Aluminum	Titanium	Composite	Composite	Composite	Composite
Focal Length	8.5 m	8.5 m	8.5 m	8.5 m	10.0 m	10.0 m
Relfector Length (P&H)	2 x 20 cm	2 x 20 cm	2 x 20 cm	2 x 20 cm	2 x 20-30 cm	2 x 20-30 cm
Nominal Reflector Diameter(s)	50 cm	50 cm±	50 cm±	50 cm±	160 cm 120 cm± 100 cm	160 cm±40 cm± 120 cm± 100 cm±
Goals	▪ Align 1 reflector pair (P&H) ▪ Evaluate mirror assy design, alignment and metrology	▪ Align 1 reflector pair ▪ Evaluate reflector ▪ Evaluate mirror bonding	▪ Align up to 3 reflector pairs to achieve <12.5 arcsec ▪ Eval. assembly gravity sag ▪ X-ray and environmental test ▪ Evaluate composite housing	▪ Align 3 reflector pairs ▪ Evaluate tooling and alignment techniques for mass production ▪ X-ray test	▪ Flight-like configuration outer module ▪ Environmental and X-ray Test ▪ Largest reflectors	▪ Demonstrate largest and smallest diameter reflectors ▪ Demonstrate module to module alignment ▪ Environmental and X-ray test
Timeframe	Q2 of FY03	Q3 of FY03	Q1 of FY04	Q1 of FY05	Q4 of FY05	Q4 of FY06

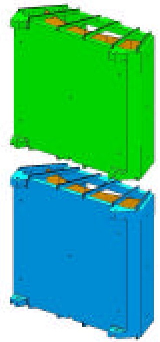
SXT Mirror Technology Development

OAP 1



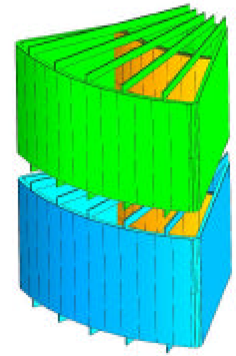
Inner Module (P&H)
Objective: Evaluate mirror assy design, alignment and metrology

OAP 2



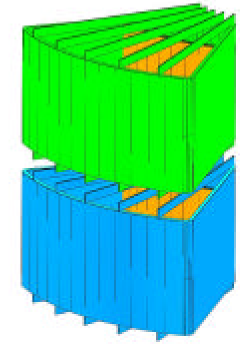
Inner Module (P&H)
Objective: Evaluate reflector, mirror bonding

EU



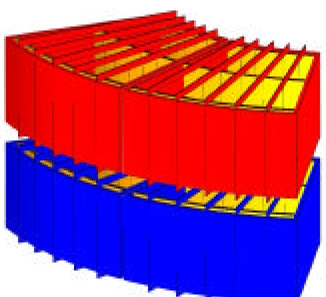
Inner Module (P&H)
Objective: Evaluate assembly gravity sag, composite housing, X-ray and environmental test

Mass Alignment Pathfinder



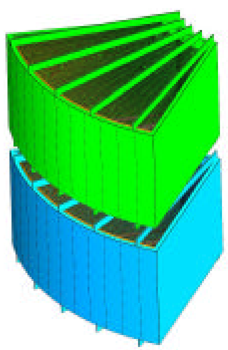
Inner Module (P&H)
Objective: Evaluate tooling and alignment techniques for mass production, X-ray test

Prototype Outer Modules



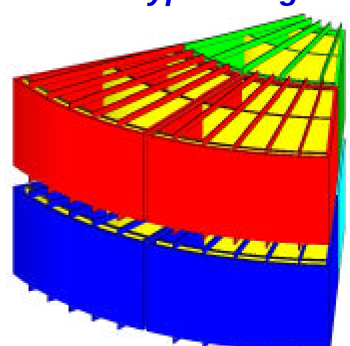
Outer modules (P&H)
Largest reflectors
Objective: Evaluate flight-like configuration outer module, X-ray and environmental test

Prototype Inner module



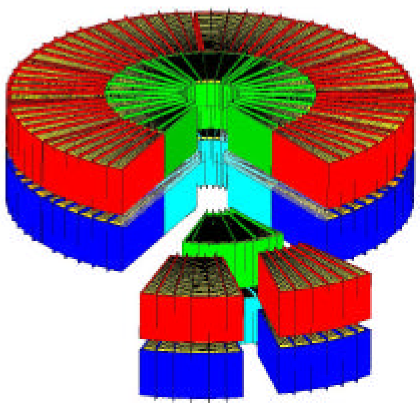
Inner module (P&H)
Objective: Evaluate flight-like configuration inner module

Prototype Wedge



Two outer modules + one Inner module (P&H)
Objective: Evaluate flight-like wedge, X-ray and environmental test

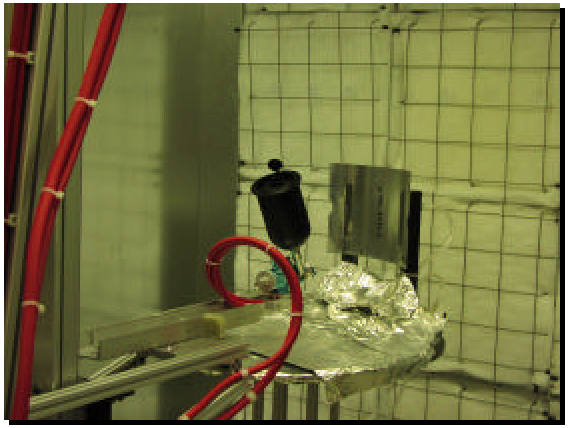
Flight Mirror Assembly (FMA)



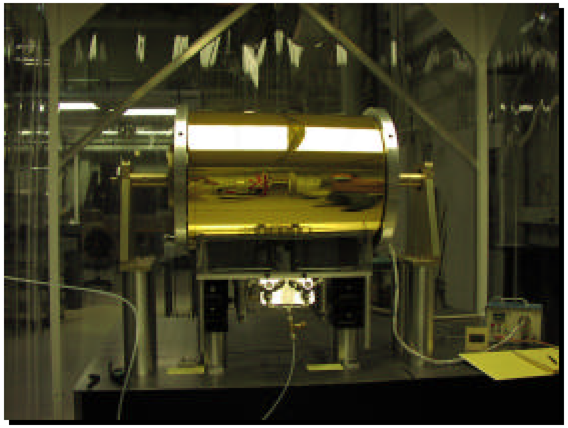
SXT - Recent Progress

- *Technology Roadmap refined as part of TRIP activity*
  - *Looking to earlier industry involvement - partnership during prototype development*
- *Substantial progress toward making 50 cm reflector segments that meet requirements*
  - *Reflector fabrication has emerged as critical path to meeting angular resolution requirement; 20 cm diameter segments consistently meet requirement*
  - *Performed replication facility rework to remove contamination (mainly dust)*
  - *Modified epoxy application approach - applied as axial strips*
  - *Reflector quality is now limited by forming mandrel quality*
- *Took delivery of 1.2 m replication mandrel from Zeiss; acceptance metrology of 1.6 m mandrel nearing completion*
- *OAP1 work completed - demonstrated ability to reproducibly manipulate and align reflectors*
- *OAP2 work underway - learning how to bond reflectors; environmental test is pending*
- *Engineering unit concept being revised; new housing material selected*
- *Mass production pathfinder concept being developed*
- *Preparations nearly complete at MSFC stray light facility for X-ray characterization*
- *Major project milestone is performance demonstration; goal is end of year*

Reflector Replication

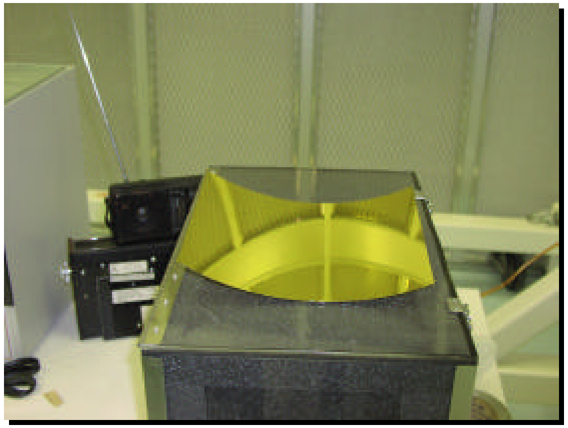


Robotic spraying of substrate



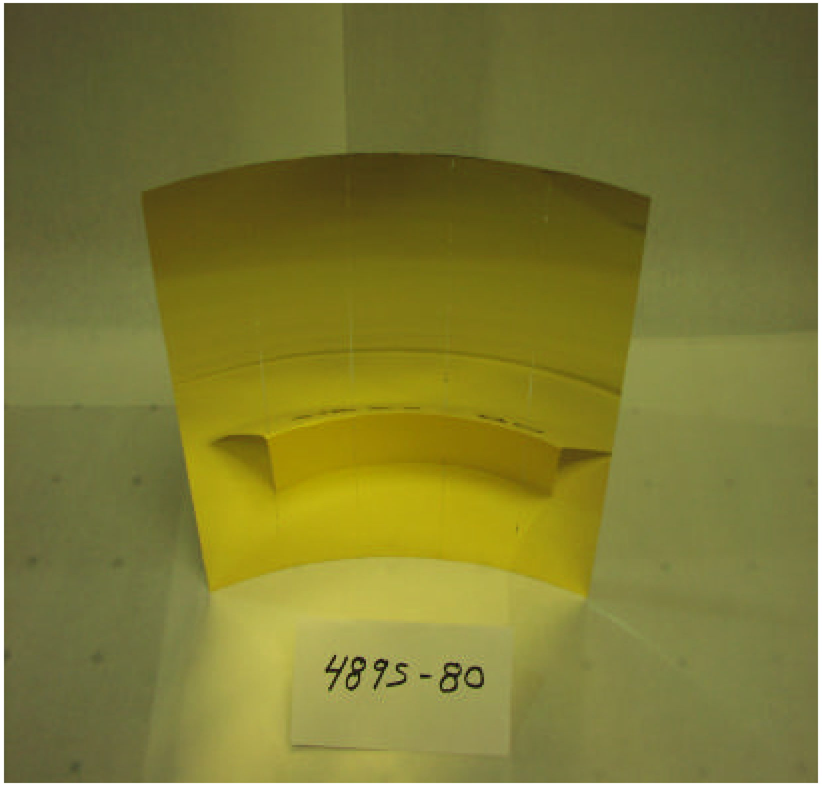
Attachment of substrate to mandrel in vacuum

Removal of finished reflector after curing



Finished reflector

Reflector Fabrication Process Improvement

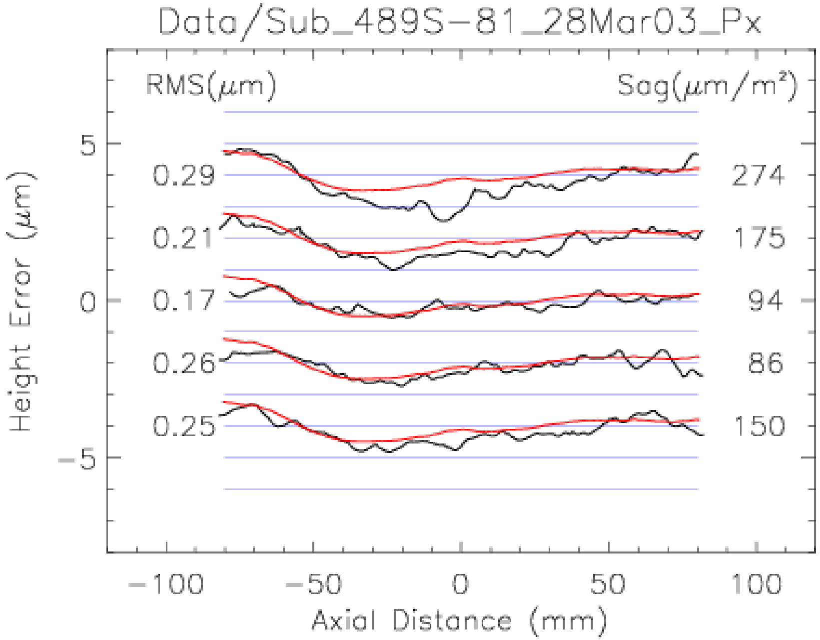


- Dust and other contamination reduction have resulted in high quality substrates
- Epoxy segmentation during replication has resulted in significant stress reduction, leading to good reflector figure

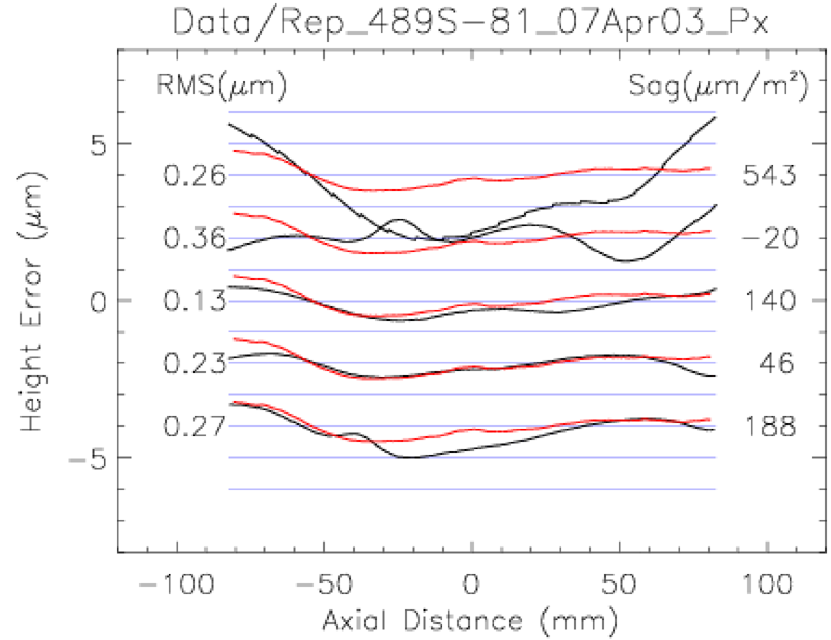
Reflector Axial Figure is Limited by Forming Mandrel Quality

Comparison of Substrate and Replica with Forming Mandrel

Substrate

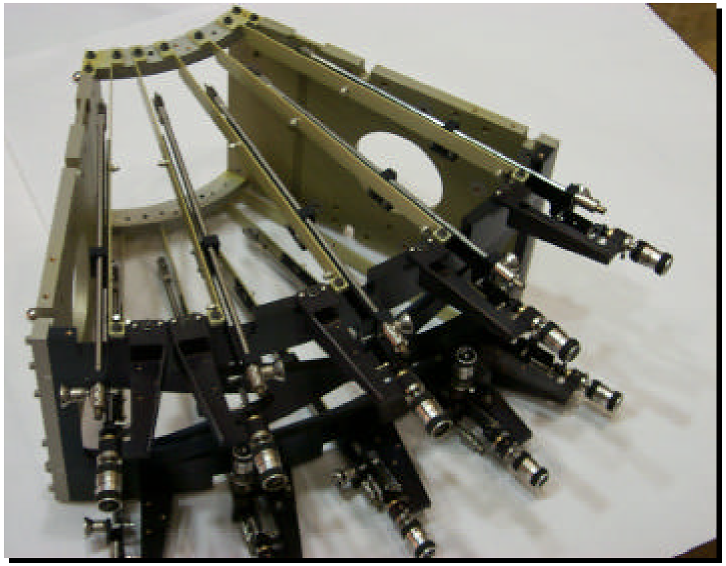


Replica

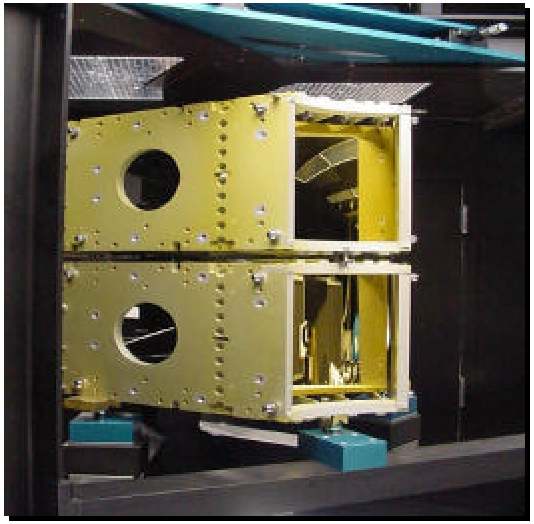


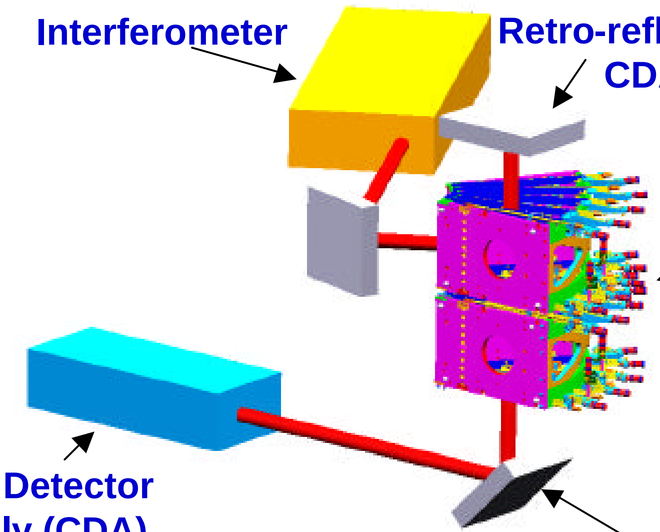
- **Red line represents axial profile of forming mandre; axial profiles at five different azimuthal positions of reflector are shown.**
- **Substrates conform to forming mandrel within 0.25 micron rms.**
- **Epoxy replication smooths out the mid-frequency ripples of substrates. Replica figure resembles that of the forming mandrel to a high degree.**
- **Residual distortion is still visible. It will be mitigated by a new epoxy cure cycle and a new method for separation from the replication mandrel.**

OAP1 Housing and Alignment



- Alignment scheme incorporates five independent positioners, top and bottom, plus two vertical positioners
- Interferometer viewing through window in hub provides feedback on figure distortions
- Centroid Detector Assembly (designed for Chandra mirrors) used to determine focal point and reflector distortions





Summary of lessons learned with OAP-1

- Satisfactory alignment quality can be achieved with CDA and in-situ axial interferometry
- Small differential adjustments of actuator pairs changes local average slope, but not local axial figure
- Common mode adjustments change 2nd order axial figure, but not local slope
  - Axial sag changes at ~0.2 microns per micron of common mode adjustment.
  - An adjustment at one position will effect the sag at least as far as the neighboring sets of actuators
- Common mode adjustments of all OAP actuators simultaneously yield little change in axial figure

Deformation of replica vs single actuator

- Moving one actuator at the center of a replica results in some deformation across the entire optic
- Propagation of deformation appears to be severely dampened at neighboring actuator positions

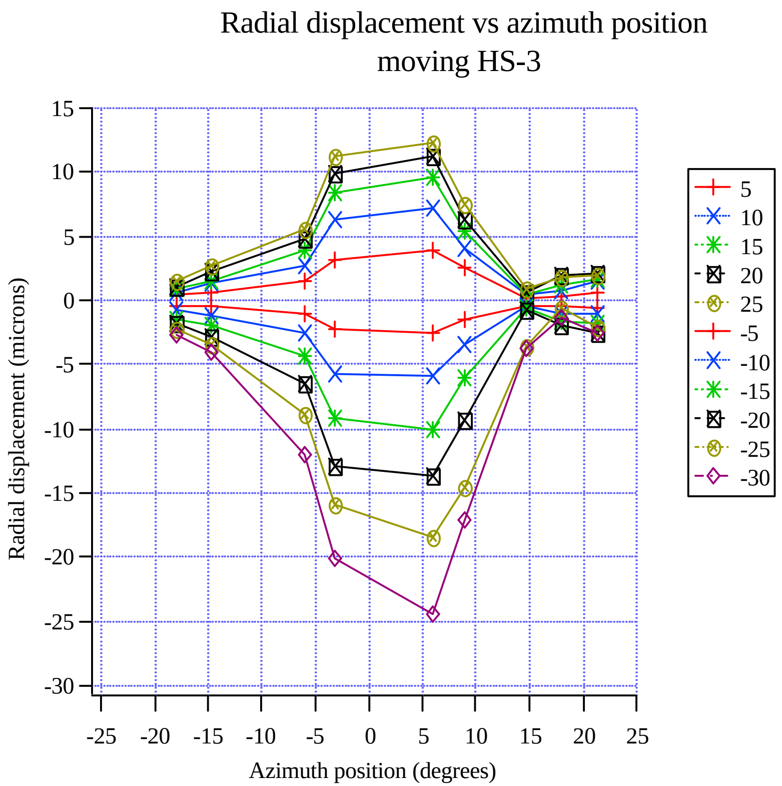
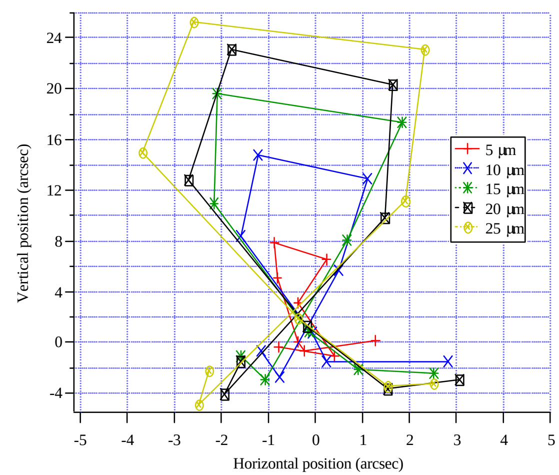


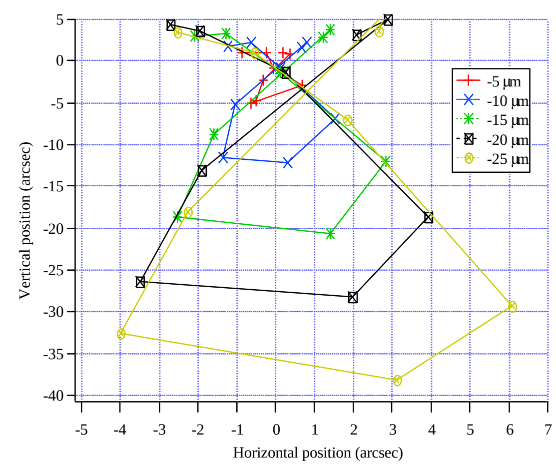
Image response vs single actuator

- Moving a single actuator deforms the focusing quality over the entire replica
- Assuming perfect focusing (nulling the positions of all return beams at the CDA), the focal plane image deforms in an expected manner

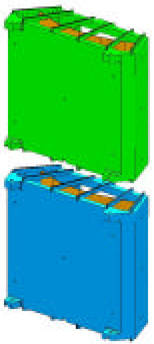
Focal plane spot deviation vs single actuator movement
HS-3 (bottom center H actuator, increasing radius)



Focal plane spot deviation vs single actuator movement
HS-3 (bottom center H actuator, decreasing radius)



OAP2 Development



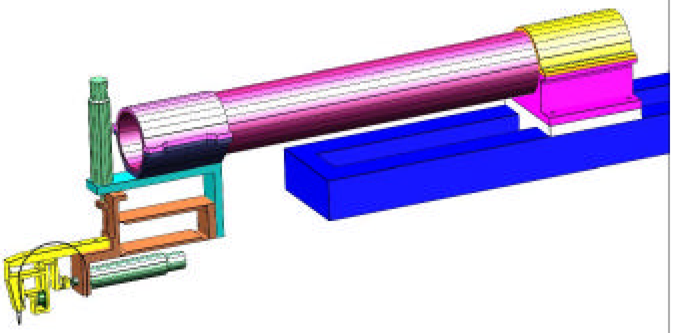
- Dry Run #1 Mirror Installation
  - Successfully used Fixed CMM to radially locate the mirror to within 2.5 microns
  - Completed installation of the first silvered substrate into the OAP2 P housing
  - Bonded struts for the first time using 5 minute epoxy and Stycast 2850
  - Procedure changes based on this experience are in work
  - Results from the CDA testing showed that the mirror bond points moved after bonding. This may be a result of bond shrinkage or the thermal change over the test time may have influenced this measurement. Hence the next dry run.
  - Successfully removed epoxies from OAP2 housing and strut in preparation for next dry run
- Dry Run #2 Mirror Installation
  - Plan is to perform second dry run to better evaluate the mirror alignment post bonding, pathfind the procedures for aligning and bonding P to H housing, and perform vibe test
  - Housing and struts have been etched. Strut to housing CMM alignment/bonding currently in work
- Preliminary Vibe Test Procedure sent to team for comment
  - Purpose of Vibe test is:
    - Determining failure mode of glass mirror
    - Determine resonances of glass mirror while bonded at 10 strut interface points
    - Determine level at which mirror breaks and see if it survives to GEVS level

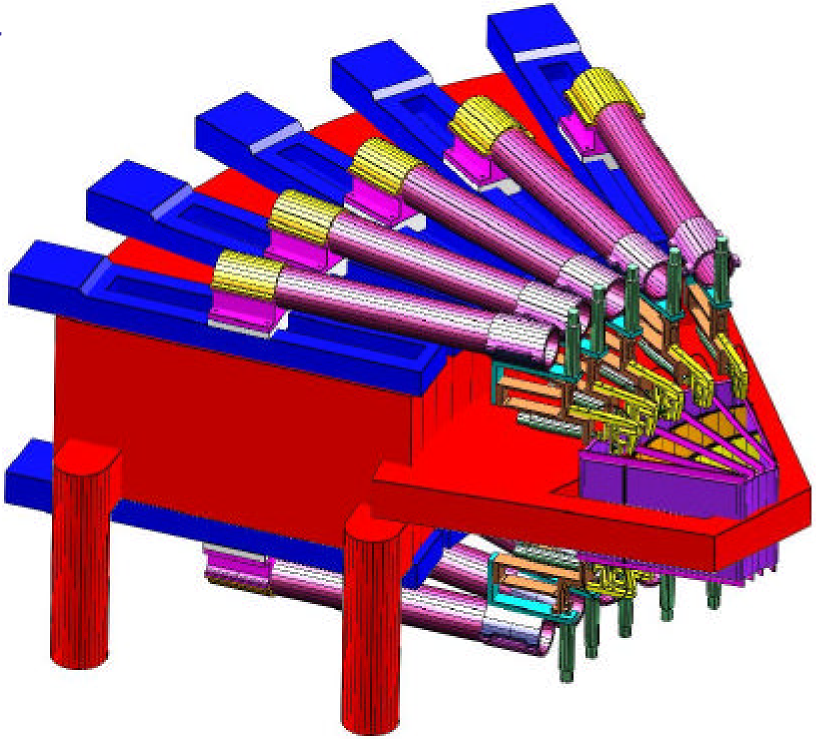
Engineering Unit Development

- **Material Trade Study for Module Design**
  - Investigated numerous materials - composite (zero-CTE and CTE-matched), metal
  - Titanium Beta-21S selected for modules and struts
      - » Need to determine heritage
      - » CTE close to Glass
    - Need to confirm that the glass CTE is 6.3 in-house at GSFC using a “flight-like” glass-epoxy-gold “sandwich”
  - Titanium Flexures between Modules and the FMA ring structure.
  - Conclusions and resulting benefits
    - Design allows for maximum mirror area
    - Limited material testing required
    - Simplified overall manufacturing process, maintains maximum in-house control, more conducive to changes
    - Design fosters a better thermal environment
    - Wall thickness can be reduced for metallic over that used by current composite laminate

Tooling for Mass Production Pathfinder

- **Mass Production Tooling:**
  - **Intent to combine precision actuator output with CDA output in computer controlled loop**
  - **Investigating this summer using a single manipulator arm**
  - **In parallel, refining requirements on etched Si microstructures**

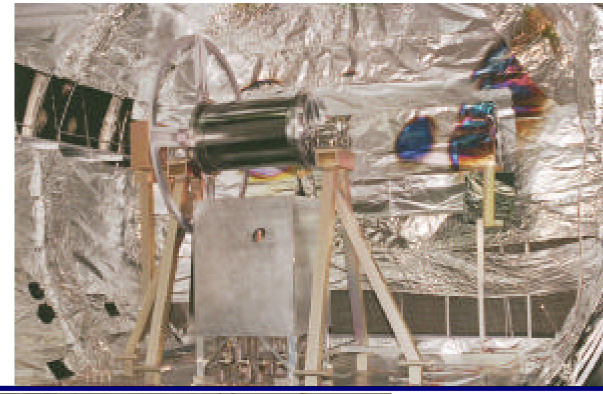




Support for SXT development

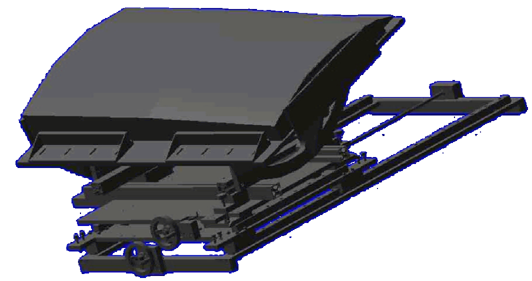
CLEANING & COATING





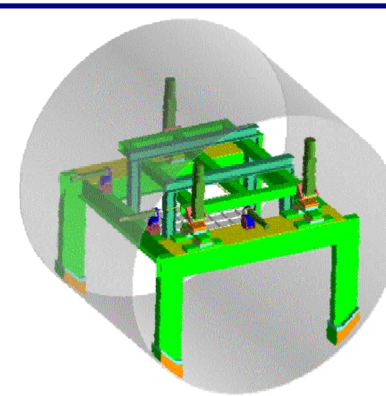

MANDREL METROLOGY





X-RAY TESTING





Precision segment mandrels

Zerodur™
30° segments
1.6, 1.2, 1.0-m diameter
1.1-m total length
0.5-m-long P|H surface
$HPD_{geom} < 4''$
$\sigma < 0.4$ nm (> 1 mm^{-1})

Constellation X

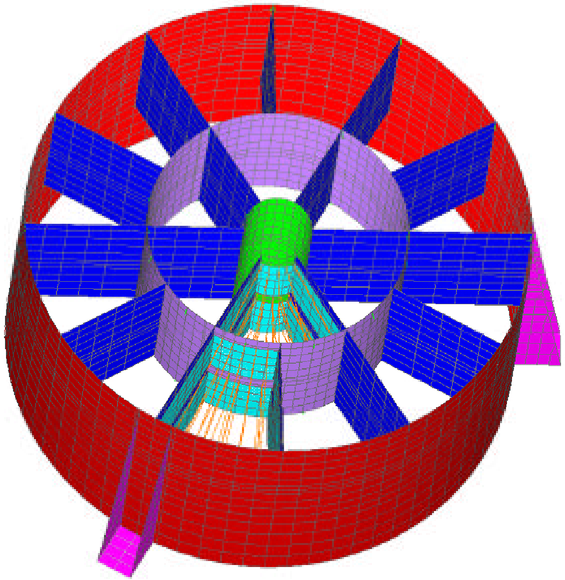
The Constellation X-ray Observatory

SXT backup slides

May 8, 2003

Stress Model Development

- **Combined structural/thermal analysis being performed to determine best approach for the EU.**
- **Overall SXT model is a super element model which is very robust due to the reduced number of nodes (17,000 vs. 100,000). Stiffness and output recovery capability is maintained. Model consists of:**
  - **Rings (Outer, Middle and Inner)**
  - **Separate P & H Inner Modules**
  - **Separate P & H Outer Modules**
  - **Mirror attachment/alignment struts**
  - **Flexures at Module to Ring Interfaces**



Stress Model currently being used to support OAP2 vibe test and for Engineering Unit Development

Engineering Unit Development

- **Material Trade Study for Module Design**
  - Stress Runs 9 & 10 underscore the diminished benefit of a composite module
    - Minimal Frequency increase. Composite weight does not include weight due to joint material. Additional weight will reduce frequency.
    - Small benefit for added complexity in design
  - Moisture dry-out does not come into play with metallic modules
  - Metallic modules will have an isotropic design (verses only quasi-isotropic with use of composites)
  - Struts and Flexures could also be machined from the same Titanium material.
    - Flexures could even be integral to the housing
  - Possible further weight savings in titanium design by machining integral ribs and/or "lightening holes" into the module walls
  - Alliant TechSystems (ATK, formerly known as COI) provided a ROM quote for fab of a Composite Engineering Unit

Engineering Unit Development (continued)

Normal Modes Summary Matrix

Analysis Run	Configuration Description				Mode 1		Mode 2		Mode 3		Assembly Weight	Assembly Mass
	Rings		Modules		Frequency	Description	Frequency	Description	Frequency	Description	(lb)	(kg)
	Material	Thickness (in)	Material	Thickness (in)	(Hz)		(Hz)		(Hz)			
1	Titanium	0.15	Titanium	0.15	18	Bending	18	Bending	20	Torsional	1359	617
2	Titanium	0.15	T300 Facesheets with 6061-T6 Solid Core	0.15	19	Bending	19	Bending	21	Torsional	1149	521
3	M55J Laminate	0.15	T300 Facesheets with 6061-T6 Solid Core	0.15	21	Bending	21	Bending	23	Torsional	929	421
4	M55J Laminate	0.15	M55J Laminate	0.15	22	Bending	22	Bending	24	Torsional	909	412
5	M55J Laminate	0.15	Titanium	0.15	19	Bending	19	Bending	22	Torsional	1140	517
6	Outer Ring M55J Honeycomb; Spokes and Inner Rings M55J Laminate	Outer Ring t = 0.66"; Laminate = 0.15"	Titanium	0.15	25	Torsional	30	Bending	30	Bending	1149	521
7	Outer and Inner Ring M55J Honeycomb; Spokes and Middle Ring M55J Laminate	Outer and Inner Rings t = 0.66"; Laminate t = 0.15"	Titanium	0.15	25	Torsional	33	Bending	33	Bending	1150	522
8	Outer and Inner Ring M55J Honeycomb; Spokes and Middle Ring M55J Laminate	Outer and Inner Rings t = 0.66"; Spokes t = 0.2"; Middle Ring t = 0.15"	Titanium	0.15	27	Torsional	33	Bending	33	Bending	1164	528
9	Outer and Inner Ring M55J Honeycomb; Spokes and Middle Ring M55J Laminate	Outer and Inner Rings t = 0.66"; Spokes t = 0.2"; Middle Ring t = 0.15"	Titanium (Changed thickness so to have same bending stiffness as T300 Laminate)	0.1	26	Torsional	33	Bending	33	Bending	1046	474
10	Outer and Inner Ring M55J Honeycomb; Spokes and Middle Ring M55J Laminate	Outer and Inner Rings t = 0.66"; Spokes t = 0.2"; Middle Ring t = 0.15"	T300 Facesheets with 6061-T6 Solid Core	0.15	29	Torsional	36	Bending	36	Bending	953*	432*

MSFC FY2003 SXT optics tasks

- **Support segmented-mirror replication experiments at GSFC.**
  - Process 0.5-m cylindrical metal mandrels made by Zeiss.
    - Are re-processing (cleaning and gold coating) mandrel 50Z1 to GSFC.
    - Will continue re-processing 50Z1, then 50Z2 for final mirrors for EU.
- **Procure and accept meter-class precision segment mandrels.**
  - Procure Zerodur™ segment mandrels for GSFC mirror development.
    - Received Zeiss mandrel A (30° segment, 1.6-m diameter) in 2002 August.
    - Received Zeiss mandrel B (30° segment, 1.2-m diameter) in 2003 April.
    - Will receive mandrel C (30° segment, 1.0-m diameter) in 2003 November.
  - Conduct acceptance inspection and metrology on received mandrels.
    - Completed metrology mount and modifications for segment mandrels.
    - Performed coordinate, long-trace, surface-texture metrology on mandrel A.
    - Will perform metrology on mandrel B (Zeiss prediction: HPD < 3"; s < 4 Å).
- **X-ray test optics.**
  - Perform x-ray testing in MSFC 100-m facility.
    - Are completing 6-DOF optics mount and preparations for x-ray testing.
    - Will perform x-ray testing and analysis of development units.